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## Structure and Composition of the Mantle

Don L. Anderson

The last four years have been a period of increased emphasis on the problems of discontinuities, lateral variations, and shear velocities in the mantle. The presence of discontinuities near 400 km and 600 km has been verified by travel time, apparent velocity, and reflection and amplitude studies; it has been shown by refraction and reflection amplitudes that these discontinuities are extremely sharp, 4 km or less. Other discontinuities, or abrupt changes in velocity gradient, have been found in the upper and lower mantle. It now appears that there are relatively few large radial stretches of the mantle that are truly homogeneous. A summary of the locations of discontinuities in the mantle is given in *Johnson [1967]* and *Whitcomb and Anderson [1970]*. A second-order discontinuity has been found near 500 km by *Helmberger and Wiggins [1971]*.

Among the new models for the upper mantle are those developed by *Johnson [1967]*, *Green and Hales [1968]*, *Archambeau et al. [1969]*, *Julian and Anderson [1968]*, *Helmberger and Wiggins [1971]*, and *Hales et al. [1970]*. New models for the lower mantle have been derived by *Johnson [1969]*, *Chinnery and Toksöz [1967]* and *Hales et al. [1968]*. Shear-velocity models have been presented by *Fairborn [1969]*, *Kovach and*

*Robinson [1969]*, *Ibrahim and Nuttli [1967]*, *Anderson and Julian [1969]*, and *Hales and Roberts [1970]*. Some of the above studies include amplitudes and  $dt/d\Delta$  as well as travel times. *Whitcomb and Anderson [1970]* used precursors to the core phase  $P'P'$  to study the fine structure of the upper mantle under the Indian and Atlantic Oceans.

*Hales et al. [1970]* found a refractor under the Gulf of Mexico at a depth of 57 km that had a velocity of 8.77 km/sec. A similar velocity had previously been found at 90 km under the central United States and under the Aleutian arc, indicating that such velocity may be a common feature of the upper mantle in regions where it is not masked or obliterated by the low-velocity zone. *Helmberger and Wiggins [1971]* have velocities of 8.7 to 8.9 km/sec between 200 and 400 km, which is consistent with a generally faster upper mantle than previously supposed.

Progress in the composition of the mantle requires laboratory as well as seismic data. The main inputs are from ultrasonic and shock wave measurements. The articles by Sammis, by Liebermann and Schreiber, and by Ahrens and Takahashi in this series summarize progress in these areas.

Ultrasonic measurements are now available for olivine, pyroxene, garnet, and spinel. These are the most abundant minerals of the upper mantle, and their densities and seismic velocities are consistent with properties of the upper mantle, except in the vicinity of the low-velocity zone. The most satisfactory explanation of the upper mantle low-velocity zone involves partial melting.

Shock wave data are now being routinely used to interpret the composition of the lower mantle. Several studies have indicated that the lower mantle is enriched in FeO relative to the upper mantle; it

Don L. Anderson is with the Seismological Laboratory, California Institute of Technology, Pasadena 91101.

may also be enriched in  $\text{SiO}_2$ , i.e., it be more pyroxene rich than the upper mantle. These conclusions are based primarily on shock wave data for two dunites and stishovite and on new lower mantle density distributions based on the inversion of free oscillation data. Shock wave data on pyroxenes are required in order to make further progress.

Anderson [1970], Wang [1970], Graham [1971], Birch [1970], Press [1970], Anderson and Jordan [1970], and Anderson et al. [1970] discuss the composition of various regions of the mantle.

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## Structure, Composition, and State of the Core

Bruce A. Bolt

#### Main Developments

Since 1967 two major advances in our knowledge of the core and core-mantle boundary have occurred. First, the giant large-amplitude seismic array (Lasa) in Montana provided convincing observations of reflections

(*PKiKP*) from the inner-core boundary (ICB); second, evidence grew that a low-velocity shell existed in *P* and *S* above the mantle-core boundary (MCB).

After the recent energetic studies of the upper mantle, there are signs of quickening geophysical interest in the physical state of the earth's core. The precise nature of the striking structural discontinuities that define the MCB and ICB is of importance to solid-state physics, to geochemistry, and to geophysics. In particular, laboratory shock-wave results must be matched against the seismological inferences.

Observatory instrumentation, especially the high-gain array facilities, has become more sensitive and suitable for probing the fine structure of the core. Previously recondite core phases like *PKKKKKP* are now regularly observed [Engdahl, 1968b].

Progress on relevant seismic wave theory has mainly

Bruce A. Bolt is with the Seismographic Station, Department of Geology and Geophysics, University of California, Berkeley 94720.